

Calcium intake, body composition, and lipoprotein-lipid concentrations in adults¹⁻³

Mélanie Jacmain, Eric Doucet, Jean-Pierre Després, Claude Bouchard, and Angelo Tremblay

ABSTRACT

Background: Recent data suggest that variations in calcium intake may influence lipid metabolism and body composition.

Objective: The association between daily calcium intake and body composition and plasma lipoprotein-lipid concentrations was studied cross-sectionally in adults from phase 2 of the Québec Family Study.

Design: Adults aged 20–65 y (235 men, 235 women) were studied. Subjects who consumed vitamin or mineral supplements were excluded. Subjects were divided into 3 groups on the basis of their daily calcium intake: groups A (<600 mg), B (600–1000 mg), and C (>1000 mg).

Results: Daily calcium intake was negatively correlated with plasma LDL cholesterol, total cholesterol, and total HDL cholesterol in women and men after adjustment for variations in body fat mass and waist circumference ($P < 0.05$). In women, a significantly greater ratio of total to HDL cholesterol ($P < 0.05$) was observed in group A than in group C after correction for body fat mass and waist circumference. In women, body weight, percentage body fat, fat mass, body mass index, waist circumference, and total abdominal adipose tissue area measured by computed tomography were significantly greater ($P < 0.05$) in group A than in groups B and C, even after adjustments for confounding variables. Comparable trends were observed in men, but not after adjustment for the same covariates.

Conclusion: A low daily calcium intake is associated with greater adiposity, particularly in women. In both sexes, a high calcium intake is associated with a plasma lipoprotein-lipid profile predictive of a lower risk of coronary heart disease risk compared with a low calcium intake. *Am J Clin Nutr* 2003;77:1448–52.

KEY WORDS Calcium, body weight, adiposity

INTRODUCTION

Human studies have shown negative relations between high calcium intake and obesity-related metabolic disorders such as hypertension (1–4) and diabetes and insulin resistance (3–7). Other data show an inverse association between calcium intake and body weight (8–10) and the risk of becoming obese (11). Furthermore, some research groups have reported an inverse association between calcium consumption and body fat, particularly in women (10–12) and in children (13–15). Finally, animal models have provided mechanistic insight as to how low calcium intakes could influence body fat stores (11, 16, 17).

The plausible relation between the amount of calcium ingested in the diet and adipocyte intracellular calcium [Ca^{2+}], was examined by Zemel et al (4, 11, 18, 19). In brief, an inverse relation between dietary calcium and [Ca^{2+}], was found. It appears that an increase in dietary calcium intake results in a decrease in [Ca^{2+}], which in turn increases lipolysis (11). In contrast, low calcium consumption induces

high blood parathyroid hormone and 1,25-dihydroxyvitamin D concentrations, which could increase [Ca^{2+}], in human adipocytes, switching their metabolism from lipolysis to lipogenesis (4, 11). Thus, an increase in [Ca^{2+}], appears to promote triacylglycerol accumulation in adipocytes by exerting a coordinated control over lipogenesis and lipolysis (18). The increase in [Ca^{2+}], would suppress the latter, resulting in lipid storage and adipocyte hypertrophy.

Most of the data on calcium intake and body composition in humans are observational (9, 11, 15, 20), although the results remain useful for the formulation of new hypotheses. Furthermore, the potential relation between calcium intake and plasma lipoprotein-lipid concentrations has not been investigated. Thus, the present study was performed to further investigate the relation between daily calcium intake and direct measures of body composition as well as to test the hypothesis of an association between dietary calcium intake and plasma lipoprotein-lipid concentrations.

SUBJECTS AND METHODS

Subjects

This study is based on data obtained from 235 men and 235 women aged 20–65 y, who were recruited in phase 2 (1991–1998) of the Québec Family Study. Subjects who regularly consumed vitamin or mineral supplements were excluded from the study. However, the questionnaire on food habits that was used in this study did not permit us to specifically identify calcium supplement consumers among the subjects who reported consumption of nutrient supplements. Therefore, consumers of all types of dietary and nutrient supplements were excluded. For some analyses, participants were divided into 3 groups on the basis of their daily calcium consumption: group A (<600 mg), group B (600–1000 mg), and group C (>1000 mg). The classification of subjects was a priori decided in accordance with our intent to compare subjects with either a calcium intake markedly below nutrient reference intakes or above adequate calcium intakes. The cutoffs of 600 and 1000 mg Ca/d

¹ From the Division of Kinesiology (MJ and AT) and the Department of Food Science and Nutrition (J-PD), Laval University, Ste-Foy, Québec; the School of Human Kinetics, University of Ottawa, Ontario (BD); and the Pennington Biomedical Research Center, Louisiana State University, Baton Rouge (CB).

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³ Address reprint requests to A Tremblay, Division of Kinesiology, PEPS Laval University, Ste-Foy, Québec G1K 7P4, Canada. E-mail: angelo.tremblay@kin.msp.ulaval.ca.

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TABLE 1
Descriptive characteristics of women and men divided into 3 groups by daily calcium intake¹

Variable	Women ²			Men ²		
	Group A (n = 52)	Group B (n = 113)	Group C (n = 70)	Group A (n = 36)	Group B (n = 94)	Group C (n = 105)
Age (y)	43.5 ± 1.6	38.8 ± 1.2	36.7 ± 1.5	45.3 ± 2.0	43.2 ± 1.4	37.9 ± 1.3
Body weight (kg)	82.3 ± 3.3 ^a	69.8 ± 1.9 ^b	65.0 ± 2.7 ^b	86.8 ± 3.5	83.0 ± 2.0	82.5 ± 2.0
BMI (kg/m ²)	31.8 ± 1.2 ^a	27.0 ± 0.7 ^b	25.2 ± 1.0 ^b	28.8 ± 1.1	27.7 ± 0.6	27.6 ± 0.7
Percentage body fat (%)	37.3 ± 1.6 ^a	31.3 ± 0.9 ^b	28.9 ± 1.2 ^b	24.6 ± 1.5	23.5 ± 0.9	23.7 ± 0.9
FM (kg) ³	32.4 ± 2.5 ^a	23.6 ± 1.4 ^b	19.8 ± 1.9 ^b	21.2 ± 2.4	20.5 ± 1.3	21.2 ± 1.3
FFM (kg) ³	48.9 ± 1.2	45.7 ± 0.7	44.4 ± 0.9	62.1 ± 1.5	60.8 ± 0.8	61.7 ± 0.8
Waist circumference (cm)	93.6 ± 2.6 ^a	82.0 ± 1.6 ^b	78.4 ± 2.2 ^b	98.0 ± 2.7	94.0 ± 1.6	94.2 ± 1.6
Abdominal AT (cm ²) ⁴	552.2 ± 40.8 ^a	405.7 ± 24.4 ^b	373.3 ± 33.7 ^b	356.5 ± 39.5	340.2 ± 21.9	362.3 ± 22.4
Mean calcium intake (mg/d)	448.0 ± 12.3 ^a	789.0 ± 9.9 ^b	1286.8 ± 31.3 ^c	455.0 ± 23.4 ^a	773.5 ± 11.0 ^b	1426.4 ± 36.1 ^c

¹ \bar{x} ± SEM. Variables of body composition were adjusted for age, daily energy intake, percentage dietary fat, dietary protein, and socioeconomic status by analysis of covariance. FM, fat mass; FFM, fat-free mass; AT, adipose tissue. Within a sex group, values in the same row with different superscript letters are significantly different, $P < 0.05$.

² Group A, <600 mg Ca/d; group B, 600–1000 mg Ca/d; and group C, >1000 mg Ca/d.

³ $n = 214$ women and 216 men.

⁴ Cross-sectional area measured by computed tomography.

appeared justified because they also allowed a sufficient statistical power within each group. The Québec Family Study received approval from the Laval University Medical Ethics Committee, and written informed consent was obtained from each participant.

Anthropometric measurements

Waist circumference was measured according to Lohman et al (21), whereas body weight was measured with a standard beam scale. The closed-circuit helium dilution method (22) was used to assess residual lung volume. Body density was determined by hydrodensitometry (23), and the Siri formula (24) was used to estimate the percentage body fat from body density. Fat mass (FM) was calculated from the derived percentage body fat and total body weight. Fat-free mass (FFM) was calculated by subtracting FM from body weight.

Computed tomography measurements

Computed tomography (CT) was performed with a Siemens Somatom DR scanner (Siemens, Erlangen, Germany) according to the method described by Sjöström et al (25). Briefly, subjects were examined in the supine position with both arms stretched above their head. CT scans were performed at the abdominal level (between the L4 and L5 vertebrae). Abdominal adipose tissue (AT) was calculated by delineating the area with a graph pen and then computing the total AT surface with an attenuation range of −190 to −30 Hounsfield units (25), as previously described (26).

Dietary record

Daily energy, macronutrient, and micronutrient intakes were determined by using a 3-d dietary record, as previously described (27). Information was subsequently coded, and the energy, macronutrient, and micronutrient contents of the diet were calculated with the Canadian Nutrient File (28). The dietary journal was completed on 2 weekdays and 1 weekend day.

Plasma lipids and lipoproteins

Serum blood lipids were determined from blood samples collected at 0800 after the subjects had fasted overnight for 12 h. Total cholesterol and triacylglycerol concentrations were determined enzymatically with the use of commercial kits, as described elsewhere (29). HDL-cholesterol and LDL-cholesterol concentrations were analyzed after

precipitation of LDL in the infranant fluid with heparin and magnesium chloride (30). The ratio of total cholesterol to HDL cholesterol was also derived as a lipid index of ischemic heart disease risk (31).

Statistical analysis

JMP software 3.1.6.2. (SAS Institute, Inc. Cary, NC) was used for all analyses. The values for men and women were analyzed separately. Pearson's correlations were calculated between daily calcium intake and all body-composition variables [body weight, body mass index (BMI), FM, FFM, percentage body fat, waist circumference, and abdominal AT] and plasma lipoprotein-lipid variables (HDL cholesterol, LDL cholesterol, triacylglycerol, total cholesterol, and total:HDL cholesterol). Correlations were subsequently calculated with the residual scores between daily calcium intake and body-composition variables after taking into account the effects of age, daily energy intake, percentage dietary fat, dietary protein, and socioeconomic status (total income and highest academic level). Moreover, correlations were performed with the residual scores between daily calcium intake and plasma lipoprotein-lipid concentrations after control for FM and waist circumference.

A one-way analysis of variance was used to test for differences in body weight, BMI, FM, FFM, percentage body fat, waist circumference, and abdominal AT between the groups with different calcium intakes. A one-way analysis of covariance was used to control for a series of covariates (age, daily energy intake, percentage dietary fat, dietary protein, and socioeconomic status), which can potentially affect energy balance and body weight control. The one-way analysis of variance and analysis of covariance were also used to compare the plasma lipoprotein-lipid profile (HDL cholesterol, LDL cholesterol, triacylglycerol, total cholesterol, and total:HDL cholesterol) across the subgroups of daily calcium intake with FM and waist circumference as covariates. When a statistical difference was detected, a Tukey's test was then performed to assess specific differences between groups. All values are expressed as means ± SEMs.

RESULTS

The descriptive characteristics of the 3 calcium intake subgroups, by sex, are shown in Table 1. After adjustment for age,

TABLE 2

Plasma lipid-lipoprotein concentrations in women and men divided into 3 groups by daily calcium intake¹

Variable	Women ²			Men ²		
	Group A	Group B	Group C	Group A	Group B	Group C
HDL cholesterol (mmol/L)	1.29 ± 0.05	1.36 ± 0.03	1.37 ± 0.04	1.06 ± 0.05	1.09 ± 0.03	1.11 ± 0.03
LDL cholesterol (mmol/L)	3.27 ± 0.13	3.03 ± 0.08	2.88 ± 0.10	3.43 ± 0.15	3.36 ± 0.09	3.08 ± 0.08
Triglycerol (mmol/L)	1.43 ± 0.09	1.25 ± 0.06	1.24 ± 0.07	1.86 ± 0.17	1.70 ± 0.10	1.61 ± 0.09
Total cholesterol (mmol/L)	5.19 ± 0.16	4.94 ± 0.10	4.80 ± 0.12	5.32 ± 0.17	5.20 ± 0.10	4.88 ± 0.09
Total HDL cholesterol	4.16 ± 0.14 ^a	3.81 ± 0.09 ^{a,b}	3.69 ± 0.11 ^a	5.23 ± 0.23	5.01 ± 0.14	4.64 ± 0.13

¹SE SEM. Variables were adjusted for fat mass and waist circumference by analysis of covariance. Within a sex group, values in the same row with different superscript letters are significantly different, $P < 0.05$.

²Group A, <600 mg Ca/d; group B, 600–1000 mg Ca/d; and group C, >1000 mg Ca/d.

daily energy intake, percentage dietary fat, dietary protein, and markers of socioeconomic status, the women who consumed <600 mg dietary Ca/d had greater values of body weight, BMI, percentage body fat, FM, waist circumference, and abdominal AT than did those with daily calcium intakes >600 mg ($P < 0.05$). No significant differences were found across subgroups of men. Women and men with the lower calcium intake were 6–7 y older than the group with the highest calcium intake. This finding agrees with the significant correlation that was observed between age and adiposity in both women ($r = 0.40$, $P < 0.01$) and men ($r = 0.42$, $P < 0.01$) and justifies the statistical adjustment for age in the present study.

A comparison of the plasma lipoprotein-lipid profile among the subgroups of men and women, classified by daily calcium intake, is shown in Table 2. In women, group A had a significantly greater ratio of total to HDL cholesterol ($P < 0.05$) than did group C, whereas no significant differences were observed for HDL cholesterol, LDL cholesterol, triacylglycerol, or total cholesterol between groups. No significant differences in plasma lipoprotein-lipid concentrations were found between subgroups of men.

Calcium intakes in women and men were 861.8 ± 22.8 and 1016.4 ± 30.3 mg/d, respectively ($P < 0.01$). As expected, most of the dietary calcium was derived from dairy products. In women, 61.8% of the daily calcium intake was from milk, cheese, yogurt, ice cream, pudding, desserts with milk, and soups prepared with milk. In men, 59.5% of the daily calcium intake was provided by the same dairy products. In both sexes, bread and cereals contributed 11% and 12% of daily calcium intake, respectively. Other foods contributed smaller amounts of calcium.

Simple correlations and adjusted correlations between daily calcium intake and body-composition variables in women and men are provided in Table 3. After correction for confounding variables such as age, daily energy intake, percentage dietary fat, dietary protein, and markers of socioeconomic status, significant correlations persisted only in women. Thus, adjusted correlations were significant for percentage body fat ($P < 0.01$), FM ($P < 0.05$), BMI ($P < 0.05$), and waist circumference ($P < 0.05$). Trends were also observed for FFM ($P = 0.08$). For men, after control for the same covariates, no significant association with daily calcium intake was observed.

Simple correlations and adjusted correlations between daily calcium intake and plasma lipoprotein-lipid concentrations in women and men are shown in Table 4. In women, after adjustment for FM and waist circumference, LDL cholesterol, total cholesterol, and the ratio of total to HDL cholesterol were all inversely correlated with daily calcium intake ($P < 0.05$). In men, after control for the same covariates, LDL cholesterol, total cholesterol, and the ratio of total to HDL cholesterol were also negatively correlated with calcium intake ($P < 0.01$).

DISCUSSION

This study was performed to examine the association between daily calcium intake and body composition and plasma lipid-lipoprotein concentrations in both women and men. Our results are generally consistent with recent data, which show a potential effect of calcium intake on body weight and FM in humans (8, 9, 11–15). One of the intriguing observations in the present study is

TABLE 3

Correlations and adjusted correlations between daily calcium intake and body-composition variables in women and men¹

	Percentage body fat	FM	FFM	BMI	Waist circumference	Abdominal AT ²
Correlations						
Women, calcium intake	-0.17 ³	-0.11	0.01	-0.07	-0.07	-0.17 ³
Men, calcium intake	-0.20 ⁴	-0.10	0.25 ⁴	0.00	-0.05	-0.02
Adjusted correlations ⁵						
Women, calcium intake	-0.19 ⁴	-0.17 ³	-0.12 ⁵	-0.14 ²	-0.15 ²	-0.10
Men, calcium intake	-0.10	-0.09	0.02	-0.09	-0.10	0.04

¹FM, fat mass; FFM, fat-free mass; AT, adipose tissue.

²Cross-sectional area measured by computed tomography.

³ $P < 0.05$.

⁴ $P < 0.01$.

⁵After correction for age, daily energy intake, percentage dietary fat, protein intake, and socioeconomic status.

⁶ $P = 0.08$.



TABLE 4

Correlations and adjusted correlations between daily calcium intake and plasma lipid-lipoprotein concentrations in women and men

	HDL cholesterol	LDL cholesterol	Triglyceride	Total cholesterol	Total:HDL cholesterol
Correlations					
Women, calcium intake	0.06	-0.20 ¹	-0.13 ²	-0.19 ¹	-0.19 ¹
Men, calcium intake	0.10	-0.24 ¹	-0.11	-0.24 ¹	-0.22 ¹
Adjusted correlations ²					
Women, calcium intake	0.03	-0.18 ¹	-0.08	-0.16 ²	-0.15 ²
Men, calcium intake	0.09	-0.26 ¹	-0.11	-0.26 ¹	-0.24 ¹

¹ $P < 0.01$.² $P < 0.05$.³ After correction for the effects of fat mass and waist circumference.

that the significant relations with dietary calcium were observed mainly in women. These observations, however, agree with those of Teegarden et al (12) and Zemel et al (11). As shown in Table 1, body weight, BMI, percentage body fat, FM, waist circumference, and abdominal AT were all significantly greater in women reporting a low calcium intake (<600mg/d). This was observed despite adjustments for a series of potentially confounding variables.

As proposed by Zemel et al (4, 11), a low calcium intake could also influence calcitropic hormones. In humans, a rise in parathyroid hormone and 1,25-dihydroxyvitamin D favors an increase in $[Ca^{2+}]$, promoting lipogenesis (4, 11). Conversely, a high calcium intake results in lower blood parathyroid hormone and 1,25-dihydroxyvitamin concentrations and an increase in lipolysis (4, 11).

Our study is the first to show a difference in the lipoprotein-lipid profile by daily dietary calcium intake, independently of adiposity. Thus, in women and in men, LDL cholesterol, total cholesterol, and the ratio of total to HDL cholesterol were inversely correlated with daily calcium intake. The ratio of total to HDL cholesterol was significantly greater in women who consumed lower amounts of calcium (groups A and B) than in group C (Table 2). Accordingly, a recent study of postmenopausal women showed a beneficial effect of calcium citrate on blood lipids (32). These data strongly suggest that the effects of calcium on the lipolysis-lipogenesis balance as well as on plasma lipid and lipoprotein concentrations warrant further investigation.

Zemel et al (11, 16) studied the implication of the agouti protein on the regulation of $[Ca^{2+}]$. Agouti stimulates Ca^{2+} influx and promotes energy storage in adipocytes by stimulating the expression and activity of fatty acid synthase, an enzyme involved in lipogenesis, and by inhibiting lipolysis in a Ca^{2+} -dependent rat model (11). This model is useful for the assessment of calcium regulation in adipocytes of rodents, but human studies are also needed to test these pathways.

The relation between dietary calcium intake, adiposity, and lipoprotein-lipid metabolism may also be affected by sex hormones. Indeed, variations in plasma estrogen concentrations were recently found to be associated with those in intestinal calcium absorption (33, 34). This could affect dietary calcium availability and result in significant metabolic changes long term.

As we reported previously, men who consumed micronutrient supplements had a lower mean body weight (8.5 kg) than did non-consumers of supplements (35). Thus, we could expect a potential role of other micronutrients on variations in energy balance and body composition. Nevertheless, the influence of calcium on daily and resting energy expenditure and on feeding behavior (eg, level of satiety, level of hunger, desire to eat, and prospective food consumption) should be considered in future research.

As expected, dietary calcium was mainly provided by dairy products in both men and women. Because these foods are good sources of fat and protein, which are known to affect both energy balance and adiposity (36, 37), analyses were performed by correcting for variations in these 2 nutrients. However, as indicated above, this statistical adjustment did not alter the calcium-adiposity relation, suggesting that the potential effect of calcium on body fatness and lipid metabolism is independent of the macronutrient content of dairy products.

In summary, dietary calcium intake is associated with body composition, particularly in women who report a low calcium intake. Moreover, the plasma lipoprotein-lipid profile in both women and men is apparently affected by a low calcium intake, independently of the concomitant variation in body fatness. We conclude that dietary calcium should be considered in the study of the regulation of energy balance if a more complete picture of the factors predisposing to obesity is to be achieved. More research is needed to establish whether there is a causal association between calcium intake, body composition, and plasma lipoprotein-lipid concentrations.

MJ reviewed the relevant literature, performed the statistical analyses, interpreted the data, and drafted the manuscript. AT, J-PD, and CB were involved in the study design and data collection and revised the manuscript. ED contributed to the statistical analyses and to the interpretation of the global issue of micronutrient supplementation and revised the manuscript. None of the authors had a personal interest or a potential personal conflict.

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